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Noise Control of Hand-Held Power Tools

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1. INTRODUCTION

The prevention of hearing loss in the workplace remains a primary motivation for noise control engineering studies. Among the great variety of workplaces where noise exposure may be hazardous, construction sites have received relatively little attention due to the fragmentation of the industry, the difficulty in enforcing any regulations, and perhaps also the belief that little can be done about noise emissions inherent to the operation of power tools. It has been reported that over 6 million construction workers are exposed to potentially harmful noise emissions on a daily basis. Reportedly, a significant number of construction workers may suffer from hearing loss or other hearing disorders. Ambient noise may also have other undesirable effects such as masking useful sounds or warning signals. Present regulations arguably do not adequately address this problem.

More attention should be paid to the noise emissions of the power tools themselves. Noise control at the source is the preferred noise control strategy. It is difficult on a construction site in constant evolution to address sound propagation issues, and the enforcement of a noise abatement program including the wearing of hearing protection devices is also difficult.

The objectives of the present study were:

(1) to measure the acoustic emissions of two selected hand-held power tools
(2) to identify the primary sound generating mechanisms
(3) to identify, design, and implement one noise control solution
(4) to evaluate the effectiveness and the cost of the selected solution

Two tools were selected for this particular case study. The projects were carried out over the course one semester by four teams of undergraduate students in the context of a class project for an undergraduate introductory course on noise control. The participating students were from the schools of mechanical engineering, aeronautics and astronautics, electrical engineering, agricultural engineering, acoustical engineering, and physics. The teams were formed at the start of the semester and the students worked on the projects in addition to their normal activities.

2. PROBLEM DEFINITION

A. Tools Information

Tool A
- Brand: Milwaukee
- Model: Variable Speed 1/2" D.I. Impact Wrench
- Catalog Number: 9072-20

Tool B
- Brand: Bosch
- Model: Top handle jig saw
- Catalog Number: 1587 AVS

B. Operational Description

B.1. The impact wrench

The first tool considered was a 2.7 kg electric impact wrench capable of producing a 67.4 N·m torque. It has a 7.0 A motor that entrains an impact gear mechanism at 1800 rpm. A picture of the impact wrench is shown in Figure 1. A switch and dial indicator allow adjustments of the current to select the operational direction and speed, respectively. The electric motor entrains a drive shaft. Because of friction and Joule heating, the armature, brushes and electric motor create heat. A radial fan, connected to the drive shaft, cools the electric motor, armature, and other components in the rear section of the tool by drawing air in axially from the rear of the housing and along the components of the electric motor, and discharging it in the radial direction through slots in the wrench casing. The drive shaft entrains a sun gear, which is connected to the first set of planetary gears which entrains a second set of planetary gears. The gear ratio converts the high angular frequency, low torque input into a low angular frequency with a high torque output. The gears drive a hammering mechanism which is connected to a torque spring.

When the bolt which the wrench is tightening is loose, in other words when there is no torsional load, the wrench continuously turns the bolt. As the bolt is tightened, the hammering mechanism stops turning (it locks up) and begins to store energy in the torque spring. Eventually, the torque spring then releases energy back to the hammering mechanism, releasing the gear which causes an impact when after one-half rotation the gear teeth become engaged again. This occurs repeatedly at a frequency of about 30 Hz, causing intense "ratcheting" sounds.

B.2. The jigsaw

The top handle jig saw is a small power hand saw with a slim blade that can be used to cut straight lines and curves. It is 27.9 cm long and weighs 2.5 kg. A picture of the jigsaw is shown in Figure 2. A 120 volt AC electrical power source is fed into the electric motor in the middle portion of the saw. The electric motor speed may be varied using settings and controls. An electric motor entrains a series of gears and transmission components. An integral part of this transmission is the counterbalance plate, which slides up and down on bushings preventing large oscillations of the center of mass of the saw. This is necessary because of the offset crank which converts rotational motion into translational motion of the pushrod. This pushrod is guided by bushings and a roller assembly to support the forces imposed during operation. Finally, connected to the pushrod is the saw blade itself. One of the main secondary systems is the cooling fan and associated airflow path. Air is drawn in through the motor housing cover. From there, it is drawn across the motor by a fan, cooling the electrical coils in the process. A deflector exhausts most of the air through the gap between the motor housing and gear housing assemblies. A portion of the air is deflected downwards toward the cutting surface through a three-position nozzle. The blade lock assembly utilizes a rotating sleeve and a series of washers and springs to secure the blade in the pushrod during operation. As the pushrod travels up and down, two springs are compressed and extended, keeping tension on the blade lock mechanism. The adjustable cast aluminum base acts as a foundation for the saw when in operation. It can be adjusted both forwards and backward and through +/- 45 degrees of miter angle. The base also contains an air duct which directs the flow toward the blade, keeping the cutting surface clear of debris.

3. DESCRIPTION OF THE NOISE CONTROL SOLUTION

A. The impact wrench

Five possible noise control solutions were considered based on three postulated sound generation mechanisms: air flow through the motor and fan, impacting mechanism, and gear noise. Preliminary measurements showed that the radiated sound pressure levels peaked within the frequency range of 0 to 100 Hz. This frequency range was selected as the target range for implementing a solution.

A torsional dynamic vibration absorber was selected as the datum. One of the other possible solutions considered was to add damping material within the handle. Although this would have been a safe and economical solution, it would have been effective only for high frequency noise. A second considered solution was to reduce airflow noise. However, since low frequency noise was dominant, the reduction of flow noise was deemed unworthy, since flow noise was high-frequency. Placing an internal damper around the impact mechanism would have served as a means of reducing low frequencies; however, due to space limitations and possible interference with rotating components, this idea was discarded. A muffler was the final design option. Due to the large wavelengths of the low frequency noise, an enormous muffler would have been needed, and therefore this was not deemed a feasible solution.

An accelerometer was used to determine the optimum frequency at which to tune the damper, according to the following procedure. The unloaded, unmodified tool was operated at the maximum RPM of 1800. This corresponded to a frequency of about 30 Hz. The accelerometer measurements showed peaks at 30 Hz when positioned in the longitudinal, lateral, and vertical directions. Since each of the measured perpendicular frequencies equaled the given rotational excitation frequency, it was obvious that the measured signals were in-phase.

Therefore, the fundamental torsional vibration of the tool was 30 Hz, and this was chosen as the target tuning frequency for the dynamic absorber.

Because of material availability limitations, however, it was not possible to tune the absorber very accurately. The actual torsional vibration absorber, made using available parts and resources, is shown in Figure 3. The black rubber was secured to the impact wrench housing with epoxy. Layers of black rubber were placed between the housing and a stainless steel ring to act as a solid rubber spring. The final dimensions of the test apparatus include a 0.005 m thick rubber spring and a 0.025 m thick steel ring. The weight of the combined impact wrench/torsional damper assembly was 6.8 kg.

B. Jigsaw

Several concepts were considered [1]. Four concepts were evaluated against a datum (base jigsaw with no modification) using a decision matrix. One concept was to cover the air intake and the air outlet with mufflers. The addition of these mufflers would attenuate sound caused by turbulent airflow. The main drawback of the muffler was its large size and poor performance for low frequency noise. The second concept was an insulated handle. This simple correction would attenuate some of the vibrations in the tool transferred to the hand-arm system of the operator, thus making it more comfortable to use and potentially more quiet. The third concept was a hard PVC cover for the metal casing of the jigsaw where most of the vibrations were thought to originate. This concept was aimed at reducing the noise emissions of the blade/face plate unit. The final concept evaluated was a blade guard damper. Padding would be placed at the base of the jigsaw, where the blade guide plate rests on the wood. This idea was created to address the issue of the blade guard causing excess vibration on the cutting board.

The insulating handle and the PVC face cover were chosen. These requirements were focused at reducing the most annoying noises emitted by the tool while maintaining proper function. The implementation of the design concept is shown in Figure 4.

4. MEASUREMENT METHODS

A. Sound Pressure Levels

The measurements were performed using four Realistic survey type Sound Level Meters in conjunction with a DSP SigLab digital frequency analyzer. Measurements were performed in a reverberation chamber located at the Herrick Laboratories at Purdue University. The sound level meters were calibrated using a Brüel & Kjær pistonphone type 4220.

For each measurement, the impact wrench was operated clockwise at 1800 RPM, the maximum rotational speed. A load fixture was designed and built, and acted as the test stand, following guidelines described in an ANSI standard (ANSI S12.15-1992) [2]. Fixed, non-moving loads such as bolts or nuts were found to be prone to mechanical failure. Therefore a bolt and washer assembly was used. The bolts were tight enough that the impact mechanism on the tool was engaged, but they were allowed to slip in order to prevent damage to the table and to the tool by relieving some of the torque.

Sound pressure level measurements were made in both one-third octave bands and narrow bands. A bandwidth of 20 kHz was used. Measurements were performed over a period of 4 seconds, and 50 averages were made. It was impossible to obtain the sound pressure level at low frequencies in the octave band analysis, since no more than 21 bands could be observed with averaging due to processing limitations of the digital analyzer. However, lower frequency sound pressure levels were obtained in narrow bands. The sound power levels were estimated based on the spatially averaged sound pressure levels (Lp), and the measured reverberation time of the reverberation room.

B. Acceleration Measurements

A PCB Piezoelectronics accelerometer type 018605 with an ICP Sensor Power Unit (480C02) was used. Three measurements were made on the tools both before and after modification, one for each axis: longitudinal, lateral, and vertical directions. The measurements were made without a load. Before the modification, (for the vertical and longitudinal directions) the accelerometer was placed on the gray casing directly over the impact mechanism. Afterwards, since the modification obstructed that area, the accelerometer had to be placed slightly to the side.

C. Sound power calculation

Table 1 shows the reverberation measured with B & K sound level meter type 2231 with the reverberation module. The sound power was calculated based on the spatially averaged sound pressure level measured at four different locations.

5. RESULTS

A. The impact wrench

As seen in Figure 6, post-modification tests with accelerometers placed in vertical orientation on the impact wrench show an almost complete elimination of the 30 Hz vibrational component, along with reductions at the 60 and 90 Hz harmonics. This simple correction would attenuate some of the vibrations in the tool transferred to the hand-arm of the operator [3].

While a significant reduction in the vibrational components at 30, 60, and 90 Hz is evident from accelerometer measurements, the overall sound power level exhibits only a 1 dB reduction as shown in Figure 7. This is due to the fact that the sound pressure level measurements were made with the A weighting scale, which has reduced sensitivity to very high and very low frequencies. Consequently, the significant vibration reduction at very low frequencies had little effect on the overall sound power level of the tool.

In general, this implementation of a torsional damper was quite effective for vibration control, but did not produce the desired results as far as noise control and hearing protection.

B. The jigsaw

Recordings of the sound pressure levels were made with and without the PVC face-cover while just running the saw in mid-air and while cutting through some OSB plywood. The impact of the implemented noise control device was a decrease in sound pressure levels of 4-6 dB both in idle and loaded conditions in the one-third octave band center frequency of 2500 Hz as shown in Figure 8. A 2-3 dB sound power reduction also can be seen in the overall levels for both operating conditions in the same figure.

6. DISCUSSION

A. The impact wrench

The addition of the torsional vibration absorber increased the weight of the impact wrench, but did not affect the tool's functionality. The air vents were left unobstructed so that the cooling fan could operate effectively. The accelerometer measurements on the modified tool produced excellent results, presumably because of the implemented noise control solution. However, it is possible that these results could be somewhat misleading due to inconsistencies in the measurement technique. After the modification of the tool, the location where the accelerometer was originally mounted was obstructed, and the accelerometer had to be placed slightly away from its initial longitudinal and vertical positions. Although this could have had an effect on the measurements, it is an unlikely cause of major error.

The excessive torque produced by the impact wrench posed considerable problems in the experimental setup. To prevent damage to the work-bench, the bolts used for testing were not completely tightened down, and were instead designed to slip. Although this solved the problem of excessive loads on the bolt and on the impact wrench motor, this setup made it difficult to maintain a constant amount of slipping. This resulted in inconsistent measurement conditions for the operation of the impact wrench under a load. The use of spatial averaging over 4 sound level meter locations, as well as averaging over 4 different trials should have helped minimizing this source of error.

B. The jigsaw

The PVC cover solution works well because all of the original functionality of the jigsaw remains. All of the switches are accessible, the blade can be changed, and the air intake and output are free from obstruction. The cover and handle padding do add some additional mass to the system; however this only helps reduce vibrations, and is not enough to make use of the tool uncomfortable.

The PVC cover and handle padding are inexpensive. All of the materials used were lightweight, fairly common, easy to work with, and inexpensive. A mold could be designed for the outer case and foam padding, and the two would simply need to be glued together. Straps would be attached to allow the cover to be fixed to the jigsaw. The same padding material used in the cover could be used on the handle. The modifications made to the saw were quite rough-cut. Further work could be done to improve the design. A denser foam could be added to the handle to increase the vibration reduction achieved to make the saw more comfortable for the user. In the case of the PVC cover, denser acoustical foam could be used to reduce more of the vibrations and the noise emitted from the machinery. More care could be taken to design padding that fit snugly around the tool and held tightly to the PVC shell. Fitted Velcro straps could be used, for instance, to allow the cover to be put on or taken off very easily.

7. CONCLUSION

The noise control solutions for commonly used hand-held tools were identified and implemented. The implementation of the torsional vibration damper yielded a considerable reduction in vibrations at 30 Hz with an impact wrench. However, no significant reduction in the overall sound power level occurred, due to the fact that large changes in level at low frequencies do not translate to large changes in overall sound power level when using the A weighted scale. To achieve an overall reduction in sound power levels, it is recommended that a frequency in the range of 1 kHz – 2 kHz be targeted for the torsional vibration damper. This design would be more likely to reduce noise in bands which contribute most to loudness as perceived by the human ear, which was the primary goal of this study. A higher tuned resonance frequency could be achieved by decreasing the outer radius of the steel ring, decreasing the thickness of the spring, decreasing the density of the steel, or selecting a spring material with a higher shear modulus.

Noise control solution utilizing acoustic foam for the jigsaw resulted in the decrease of overall sound pressure level by a 1.5 dB in an idle condition and 2.4 dB when cutting. An attenuation of 1.9 and 2.5 dB of sound power were achieved, respectively. The goal of attenuating the noise under 6kHz was achieved. With further work on the solution design and more professional tools, this solution has the ability to produced greater attenuation of the noise.

8. ACKNOWLEDGEMENT

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9. REFERENCES

1. Malcolm Crocker, *Reduction of machinery noise* (Purdue University, West Lafayette, IN, 1974)
2. *American National Standard for Acoustics-Portable Electric Power Tools, Stationary and Fixed Electric Power Tools, and Gardening Appliances-Measurement of Sound Emitted*, American National Standards Institute ANSI S12.15-1992, (Acoustical Society of America, ASA 106-1992).
3. J. Rakheja, "A comparison of biodynamic models of the human hand-arm system for applications to hand-held power tools," Journal of Sound and Vibration, **249**(1), 55-82 (2002)

Table 1. Room constant measured in a reverberation chamber

Freq(Hz)	T_{R20}	T_{R30}	EDT	Average
100	1.40	1.38	1.44	1.41
125	1.61	1.62	1.74	1.66
160	1.52	1.84	1.98	1.78
200	1.86	0.00	2.18	2.02
250	2.18	2.25	1.74	2.06
315	1.89	0.00	1.66	1.78
400	2.00	0.00	1.51	1.76
500	1.50	1.68	1.54	1.57
630	1.67	1.63	1.88	1.73
800	1.78	1.82	1.93	1.84
1000	1.91	1.91	1.81	1.88
1250	1.95	1.99	1.84	1.93
1600	1.93	1.96	1.96	1.95
2000	1.79	1.89	1.78	1.82
2500	1.80	1.84	1.76	1.80
3150	1.67	1.66	1.67	1.67
4000	1.45	1.40	1.40	1.42

Figure 1. Impact wrench.

Figure 2. Jigsaw.

Figure 3: Impact wrench with torsional vibration abssorber.

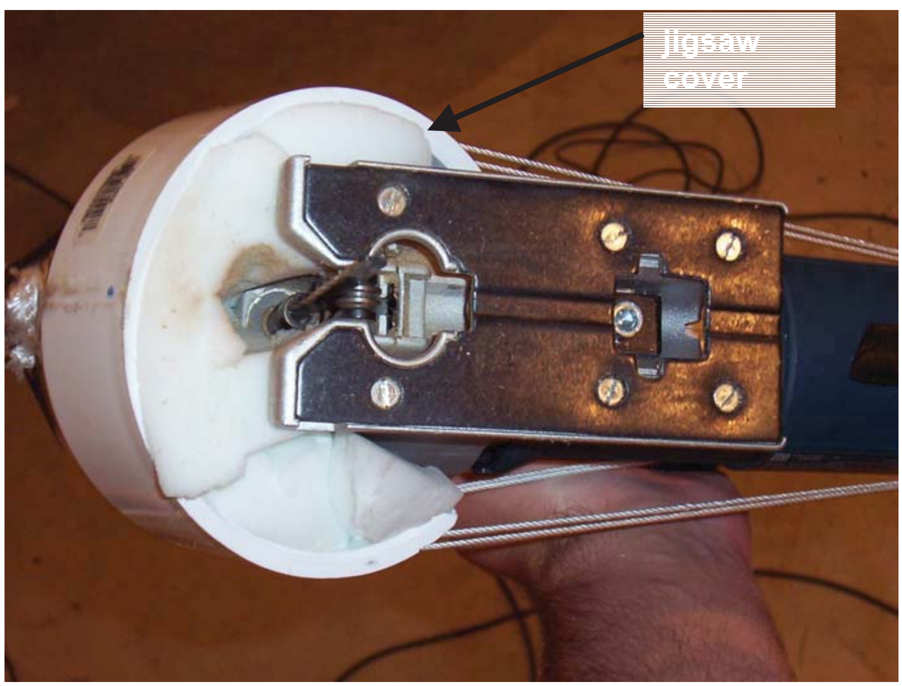

Figure 4. The jigsaw with noise reduction cover.

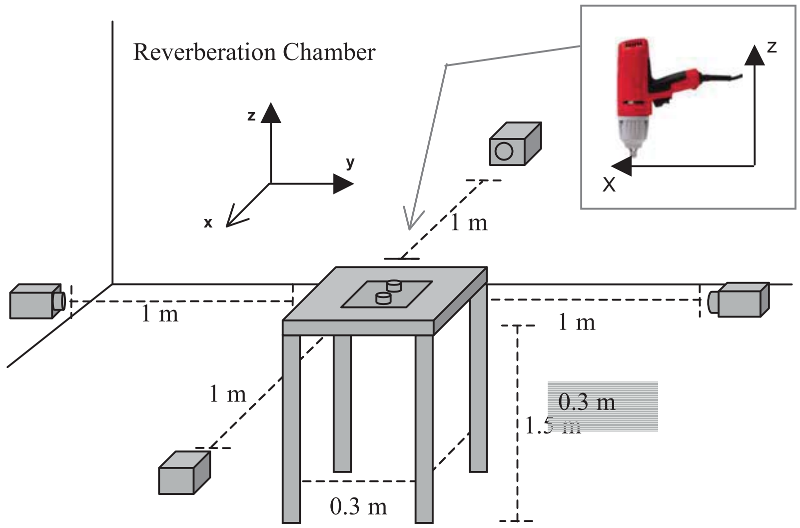

Figure 5. Experimental setup. Four sound level meters were placed 1 meter from the table in a reverberation chamber. The wrench was operated in the x-z plane as shown in the diagram.

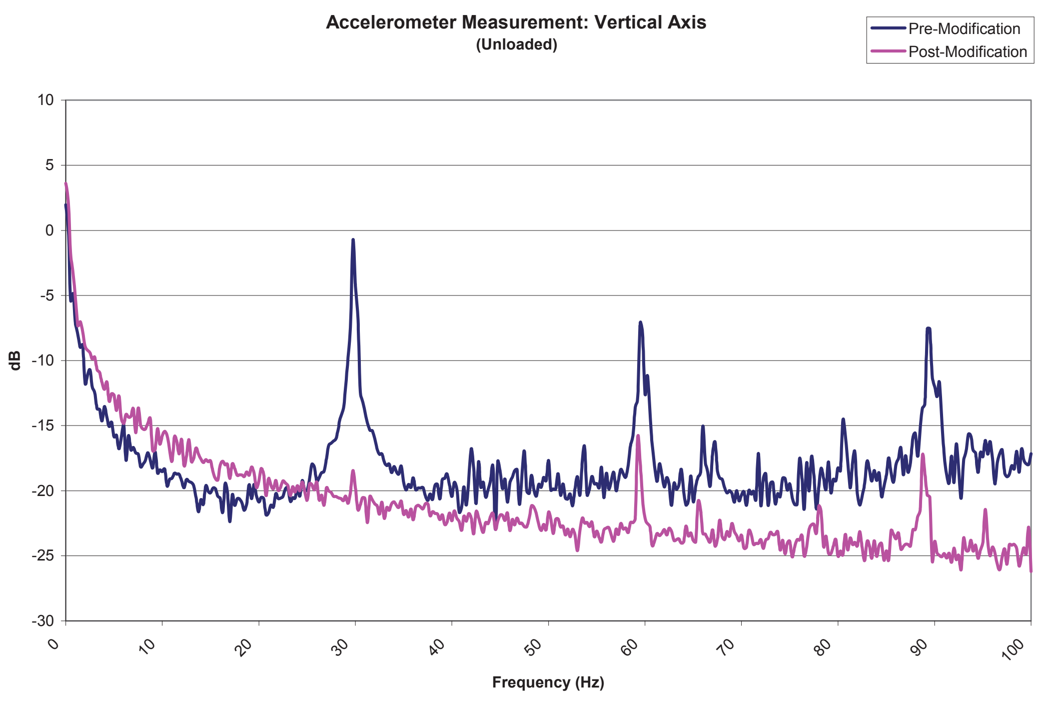

Figure 6. Spectral density of the vertical acceleration signals from the accelerometer (Blue: before the modification, purple: after the modification.)

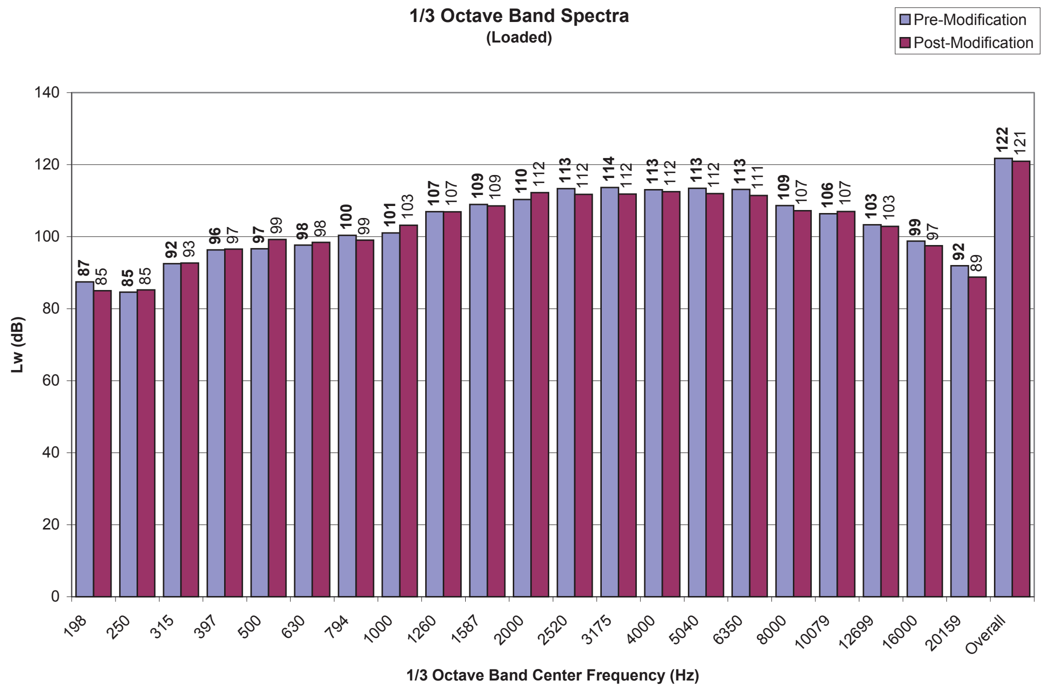

Figure 7. One third octave band spectra for the impact wrench before and after modifications.

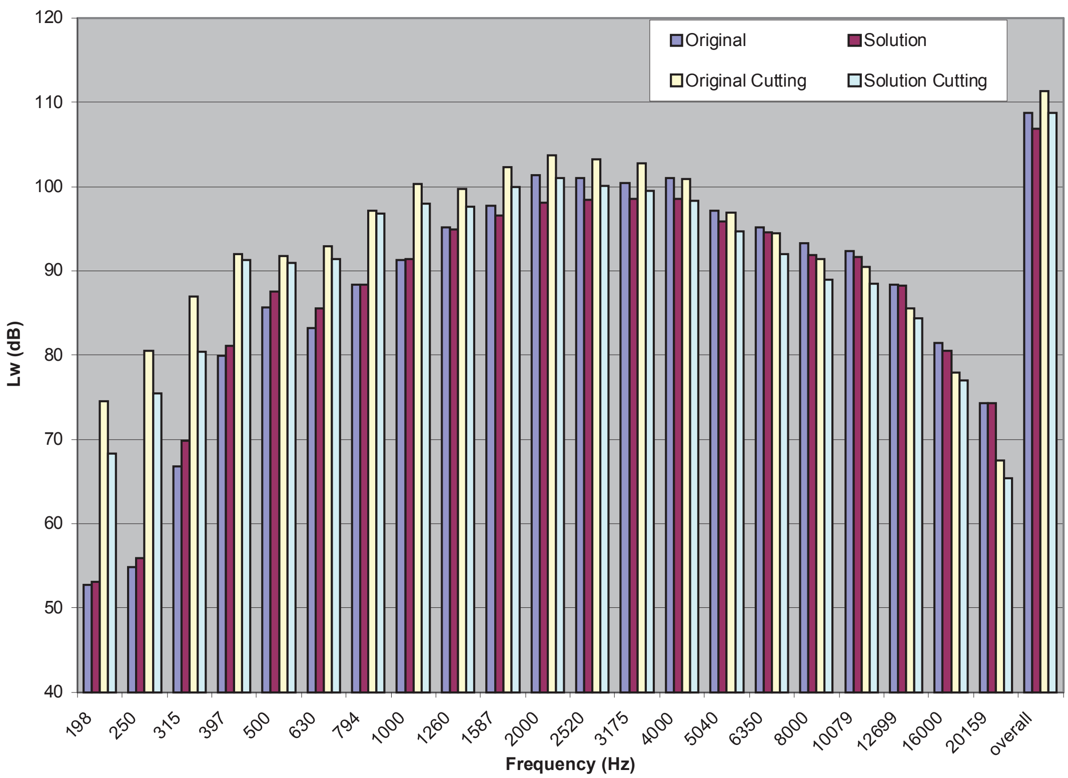

Figure 8. One third octave band spectra for the jigsaw before and after modifications.

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